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HOW TO AVOID DEFICIENCIES IN ARCHITECTURAL CONCRETE  
CONSTRUCTION(U) ARMY ENGINEER WATERWAYS EXPERIMENT  
STATION VICKSBURG MS STRUCTURES LAB

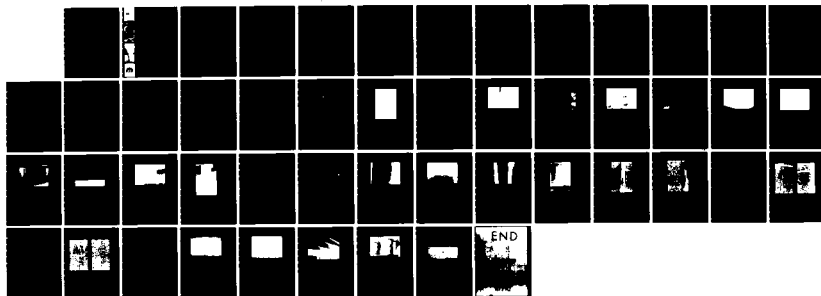
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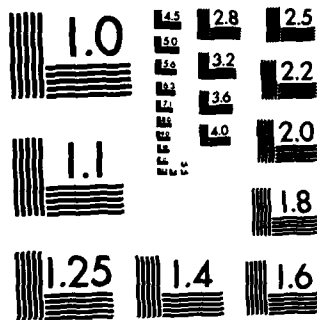
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US Army Corps  
of Engineers

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TECHNICAL REPORT SL-84-9

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# HOW TO AVOID DEFICIENCIES IN ARCHITECTURAL CONCRETE CONSTRUCTION

by

Joseph A. Dobrowolski

1601 Crest Drive  
Altadena, California 91001

and

John M. Scanlon

Structures Laboratory

DEPARTMENT OF THE ARMY  
Waterways Experiment Station, Corps of Engineers  
PO Box 631  
Vicksburg, Mississippi 39180



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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  This report documents the results of a task force assesment of defici- encies in architectural concrete construction being performed for the Corps of Engineers. A field survey of various civil works and military projects revealed 29 repetitive deficiencies for which causes are cited. Recommendations for prevention and possible repair procedures are presented in a series of fact sheets included in the report.		

## Preface

This report was prepared at the Structures Laboratory (SL) of the US Army Corps of Engineers Waterways Experiment Station (WES), under sponsorship of the Director of Engineering and Construction, Headquarters, US Army Corps of Engineers (HQUSACE), as requested by appropriation 2132050 (MCA) on 15 July 1983. The work consisted of a task force assessment of deficiencies in architectural concrete construction and in portland-cement plaster construction being performed for the Corps of Engineers. This report presents the results of the work on architectural concrete construction.

The work was conducted under the general supervision of Mr. Bryant Mather, Chief, SL, WES, and under the direct supervision of Mr. John M. Scanlon, Jr., Chief, Concrete Technology Division, SL, who served as Task Force Manager. In addition to Mr. Scanlon, members of the task force were Mr. Lou Tinnerello, DAEN-ECE-DC, who also served as Technical Monitor for HQUSACE; Mr. Michael Nash, Concrete Consultant to Al Btain District, Middle East Division (Forward); Mr. Joseph A. Dobrowolski, an industry architectural concrete consultant; and Mr. Jacob W. Ribar, an industry portland-cement plaster consultant. This report was prepared by Mr. Scanlon with input from Messrs. Nash and Dobrowolski.

Commander and Director of WES during the preparation of this report was COL Tilford C. Creel, CE. Mr. F. R. Brown was Technical Director.



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Conversion Factors, Non-SI to SI (Metric)

Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

<u>Multiply</u>	<u>By</u>	<u>To Obtain</u>
cubic yards	0.7645549	cubic metres
Fahrenheit degrees	5/9	Celsius degrees or kelvins*
feet	0.3048	metres
inches	0.0254	metres
miles (US statute)	1.609347	kilometres
square yards	0.8361274	square metres
tons (2000 lb mass)	907.1847	kilograms

\* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula:  $C = (5/9)(F - 32)$ . To obtain kelvin (K) readings, use:  $K = (5/9)(F - 32) + 273.15$ .



HOW TO AVOID DEFICIENCIES  
IN ARCHITECTURAL CONCRETE CONSTRUCTION

Introduction

1. MG A. S. Albro, Director of Engineering and Construction, Headquarters, US Army Corps of Engineers (HQUSACE), has for many years recognized that too many deficiencies have been occurring in architectural concrete and portland-cement plaster construction being performed by contractors working for the Corps of Engineers. These deficiencies have been noted on civil works construction projects as well as in military construction, and they have occurred in the Continental United States (CONUS) as well as in Saudi Arabia, Europe, Jordan, and the Far East. These deficiencies do not appear to be limited by conditions of climate, environment, or construction expediency; rather, they occur universally.

2. In an attempt to correct some of the causes of these deficiencies, MG Albro directed that the Waterways Experiment Station (WES):

- a. Appoint a manager for a task force to be comprised of a WES representative, a HQUSACE representative, a Middle East Division (Forward) representative, an industry architectural concrete consultant, and an industry portland-cement plaster consultant.
- b. Contract with industry experts in the architectural concrete and portland-cement plaster fields to assess state-of-the-art information on these subjects and prepare documentation of their assessments.
- c. Organize site visits by the task force to Saudi Arabia, Jordan, and various CONUS locations to inspect appropriate projects, interview associated personnel, and review contractor and government project documentation.
- d. Canvass industry for currently available written information and evaluate its applicability to accomplishing task force objectives.
- e. Identify new products and new materials being used in Saudi Arabia, Jordan, and CONUS and cite advantages and disadvantages of each for potential use and indicate where future product qualification is needed.
- f. Assimilate all field data, evaluations, and documentation and then prepare a report of recommended actions necessary to accomplish task force objectives. Upon HQUSACE approval, prepare necessary handbooks, specification changes, and a construction inspector's guide.

3. The following schedule was established:

- |  |           |
|--|-----------|
| <u>a.</u> Establish funding; task WES  | 18 Jul 83 |
| <u>b.</u> Complete field phase   | 1 Sep 83  |
| <u>c.</u> Complete report of field phase and<br>brief Deputy Director of Engineering<br>and Construction and staff | 15 Sep 83 |
| <u>d.</u> HQUSACE approval of field phase report   | 22 Sep 83 |
| <u>e.</u> Complete documents and brief Director<br>of Engineering and Construction and staff                       | 1 Nov 83  |

4. This report presents a discussion of the deficiencies found during the field investigations which are considered to be representative of deficiencies in architectural concrete construction currently being undertaken by the Corps of Engineers. Causes of these deficiencies, measures which can be taken to avoid such deficiencies, identification of new products and procedures, and recommended repair techniques are discussed herein.

### Scope of Field Investigation

5. The field phase of the investigation included visits to the following projects:

- a. Orleans Marina-Lake Pontchartrain Floodwall System, New Orleans, LA.
- b. Algiers Point Floodwall, New Orleans, LA.
- c. Gretna Ferry Landing Floodwall, New Orleans, LA.
- d. Tiger Island Floodwall System, Morgan City, LA.
- e. Headquarters Building, MacDill AFB, FL.
- f. Combat Readiness Command Building, MacDill AFB, FL.
- g. Hospital Retaining Walls, Fort McClellan, AL.
- h. Expansion to Reception and Processing Center, Fort McClellan, AL.
- i. RSNF O&M Community, Riyadh, Saudi Arabia.
- j. RRNSEP Project, Jeddah, Saudi Arabia.
- k. KAMA Project, Al Batin, Saudi Arabia.
- l. University of Riyadh, Saudi Arabia.
- m. KKMC Project, Al Batin, Saudi Arabia.
- n. Dining Facility, 67th and Tank Destroyer Road, Fort Hood, TX.
- o. MEDDAC Headquarters, Fort Hood, TX.
- p. Restrooms, Temple Park, Belton Dam, TX.
- q. Receiving and Distribution Warehouse, Kelly AFB, TX.
- r. Overhaul and Test Facility (Hydraulic and Pneumatic), Kelly AFB, TX.
- s. Overhead Utility Support, Kelly AFB, TX.
- t. UEP Housing (architectural concrete upgrading), Kelly AFB, TX.
- u. Aeromedical-Evacuation Training Facility (ANG), Kelly AFB, TX.
- v. Wilford Hall Medical Center, Lackland AFB, TX.
- w. Downtown River Channel Walls, San Antonio, TX.
- x. Pumping Station, Hurricane Flood Protection System, Freeport, TX.
- y. Tide Gates Structure, Freeport, TX.

6. Projects located in the southeastern United States were visited during the period 8-12 August 1983. The visit to Saudi Arabia occurred between 17 and 31 August 1983, and the southwestern United States projects were inspected during 5-9 September 1983.

## Results and Discussion

7. The quality of precast architectural concrete is generally excellent where the work is being done off site. The major problem found was that the specifications require inspection and approval when the element arrives on site. This requirement should be revised to direct an initial inspection prior to the element leaving the offsite plant. With regard to precast elements produced on site, many of the comments and recommendations presented below with regard to cast-in-place architectural concrete are applicable to these also.

8. With regard to cast-in-place architectural concrete, the Quality Assurance (QA) program is generally not working satisfactorily due to the following reasons:

- a. The specifications are not sufficiently precise or adequate to produce quality architectural concrete. If the contractor is not experienced in the production of quality architectural concrete, the final result under the present guidance will not be a satisfactory end product.
- b. The QA program does not provide sufficient guidance to the Corps project engineer as to the amount of management required for architectural concrete projects. On projects having above average management and guidance, quality architectural concrete is being produced.
- c. In some cases, inexperienced Corps personnel have been responsible for management of architectural concrete projects. Recommendations and decisions by the inexperienced personnel have produced unsatisfactory results which are difficult to correct.

9. From an analysis of the above deficiencies in the specifications and the overall shortcomings in contractor and Corps of Engineers expertise in cast-in-place architectural concrete, the following problems were identified:

- a. Poor forming practices not corrected prior to the placement of concrete. These include:
  - (1) Form leakage due to lack of or insufficient sealing of the joints.
  - (2) Offsets at form joints which lead to lack of uniformity in as-cast and treated surfaces.
  - (3) Form surfaces not maintained between placements so as to insure uniformity of surface texture and color.
  - (4) Forms used for more placements than reasonable, causing a worsening in finished appearance due to blemishes, etc.
- b. Insufficient vibration where high-range water-reducing admixtures have been used. This leads to horizontal settlement cracking which becomes accentuated with sandblasting.

- c. Insufficient supervision and training of contractor personnel during the preliminary stages. Mockup panels are not being used in training contractor crews how to achieve satisfactory results.
- d. Apparent failure of the Corps staff to insist on a proper end product due to its own inexperience. This has led to nonuniform finishing of as-cast surfaces. Due to the present specifications, there is some confusion among Corps construction personnel as to the desired end product. For instance, the Guide Specifications state that concrete shall be sacked while still less than 48 hours old. This requirement has resulted in nonuniform-colored lifts on single structures such as columns.
- e. Use of high gray cement contents, oversanded mixtures, and light-colored aggregates resulting in blotchy appearances after sandblasting. Late sandblasting has further accentuated these types of blemishes. Projects having light or white cements and a preponderance of coarse materials do not experience this contrast in colors.
- f. Offsets at lift lines with exposed aggregate concrete producing a nonuniform exposure of the aggregate due to the difference in the depth of exposure. Leakage at offsets also produces a nonuniform clustering of exposed aggregate just above the lift line.
- g. Nonuniform appearance of sandblasted ribs due to the sandblaster not varying the angle to abrade the sides of fins. Such a disparity should be perceived and corrected prior to final acceptance.
- h. Unsatisfactory fractured ribs due to the use of 1-1/2-in. rock in a 1-in. rib (even though specifications require 3/4-in. rock). No explanation was found for this change.
- i. Patching not matching the color and texture of the architectural finish.
- j. An inadequate number of crack-control (contraction) joints, causing random cracking in walls and beams. The location of the crack-control joints is, by the contract drawings, left to the discretion of the contractor; in many cases the contractor has incorporated an inadequate number of contraction joints to control the cracking.

10. Some of the foregoing deficiencies can be partially alleviated by introduction of new materials and techniques. The following are new materials and techniques which have been used successfully at King Khalid Military City (KKMC) in Saudi Arabia:

- a. Flowing concrete, having a slump of 6 to 9 in., using a high-range water-reducing admixture (HRWRA). Use of this material is described below.
  - (1) A significant recent advance in concrete technology is development of a HRWRA which can be used to produce concrete mixtures that do not suffer from rapid slump loss. This had

been a major problem with the first such admixtures to come on the market, necessitating the addition of the admixture at the back of the truck mixer on the jobsite (a situation considered unacceptable by most authorities due to the loss of control). However, experience at KKMC showed that various HRWRA available with integral retarders could be added at the central batch plant and would provide over 3 hours of workability even at temperatures of 100°F. Use of these retarded high-range water-reducing admixtures significantly improved the quality of the cast-in-place architectural concrete at KKMC.

- (2) The major advantages of using a high-range water reducer at KKMC were found to be:
- (a) The number of man-hours of direct labor necessary for a given placement was reduced.
  - (b) Flowing concrete was placed in considerably higher lifts. (At KKMC lifts 6.5 ft in height have regularly been placed.) This reduced the problem of horizontal lift lines between subsequent placements (especially beneficial on exposed aggregate work).
  - (c) On structural concrete placements, flowing concrete was dropped a maximum of 16 ft, without using a tremie, with minimal segregation or separation. This was of special benefit on highly reinforced walls and columns.
  - (d) With flowing concrete, the amount of vibration required was reduced to between 10% and 25% of that required for conventional concrete. This improved the aggregate distribution by reducing the possibility of segregation and was especially beneficial on exposed aggregate work.
  - (e) Since the mixture was more fluid with considerably higher viscosity and reduced surface tension, entrapped air was removed more easily. This resulted in fewer bug holes and imperfections and an improved appearance on smooth finishes.
  - (f) The pumpability of such concrete has been greatly improved with reduced slump loss through the pump. This was of great benefit where only marginal aggregates, with high absorption, were available.
  - (g) Such concrete was placed faster, resulting in quicker discharge of truck mixers enabling more trips per day.
  - (h) The concrete could be transported over 35 miles (for up to 2 hours) in ambient temperatures of +100°F with minimal slump loss.

(It should be noted that this experience is that recorded at KKMC. Before a project is undertaken elsewhere, it is recommended that tests with locally available materials be made to verify that similar procedures will work and comparable results can be obtained.)

- (3) Obviously, incorporation of a high-range water reducer is not a cure-all for all of the problems encountered in placement of high-quality cast-in-place architectural concrete. Some of the disadvantages of using such concrete that were experienced at KKMC were as follows:
- (a) Formwork must be far stronger. Column and wall forms must be designed to withstand a full hydraulic head due to the retardation and increased fluidity of the mixture.
  - (b) More attention must be placed on the tightness of the form joints, as the flowing concrete is more prone to leak because of its greater fluidity.
  - (c) Workers, supervisors, and inspectors must be trained in new placement and vibration techniques, which while no more difficult are considerably different. There is always a tendency to overvibrate. While this is not a concern on structural concrete or smooth finish work, it is potentially harmful on exposed aggregate finishes. Overvibration causes aggregate segregation and vertical sand streaks adjacent to the vibrator penetration if the mixture is seriously overmortared; as most are.
  - (d) Flowing concrete costs more than conventional concrete. With the addition of the high-range water-reducing admixture, the cement content can be reduced by approximately 10%. In the Middle East where cement costs approximately \$100.00 per ton, the additional cost of flowing concrete would be less than \$2.00 per cubic yard. It can be readily shown that the inherent benefits of using flowing concrete in the Middle East far outweigh the added cost of the admixture. However, for CONUS sites, especially in the warmer regions, local tests should be made.
- (4) As noted above, the addition of a high-range water reducer cannot be regarded as a cure-all for the repetitive problems which affect cast-in-place architectural concrete. Simply adding the admixture to the concrete will not make all the problems go away. Without good mixture proportioning, good mockups, good formwork, good placement techniques, good supervision and inspection, and the desire to do a good job, the addition of a high-range water reducer will be virtually worthless. However, as long as these other factors are accounted for, the addition of the admixture will be of substantial benefit. Without the incorporation of the admixture, the quality of work currently being achieved at KKMC would have been almost impossible.
- b. Use of a formliner for plain gray concrete and for exposed aggregate sandblast finishes has been found to be very beneficial. The formliner is 40- to 80-mil-thick vinyl, normally used as a floor covering, that comes in rolls 5 ft wide by 65 ft long and

is attached to the plywood forms with rubber cement. The material is easy to apply, easy to repair, and could be used up to 15 times. The cost for the vinyl in Saudi Arabia was approximately \$2.00 per square yard, which is very economical considering the number of re-uses possible.

- c. The concept of gang-forming has proven to be highly successful. One of the biggest problems, especially with sandblasted exposed aggregate finishes, is leakage through the form joints. The best way to minimize this problem is to reduce the number of joints. Gang-forming wall and beam forms in 40-ft lengths, covered with the vinyl formliner described above, solved many of the leaking joint problems.
- d. Two other types of requirements being imposed at KKMC which have greatly improved the quality of cast-in-place architectural concrete warrant mention. These are:

  - (1) Mockups. Prior to commencing actual construction, the contractor is required to construct mockups of each separate configuration of architectural concrete. This requirement is not contained in the majority of the contract specifications. Normally only a 6- by 4-ft test panel is required. In view of the importance of the appearance of the cast-in-place architectural concrete and the complicated sections and shapes involved, a simple test panel is insufficient and mockups are therefore more desirable. The following guidelines help to insure that the mockup provides meaningful information:

    - (a) Use a forming system that duplicates in every detail the one that will be used on the project, including form joints, rustications, corner details, chamfers, etc.
    - (b) Include in the mockup the same configuration of reinforcing steel that occurs in the placement. For beams and girders, use the same steel as occurs where the main steel laps. Should there be any posttensioning, incorporate the conduit in the mockup.
    - (c) Employ the same placement techniques and timing of lifts, vibration, etc., and the same equipment as will be used on the project.
    - (d) Strip the forms at the same time as they will be stripped on the project and use the same curing technique.
    - (e) Use the same finishing technique and timing of finishing as will be used on the project.
    - (f) Carry out the same repair technique as will be used on the project, experimenting as necessary.
    - (g) Should the mockup not be satisfactory, have the contractor do it again.



- (h) Upon completion of a satisfactory mockup, have the contractor fully document his technique and operation. Review this written procedure with the contractor and have him redo it should this not be an accurate reflection of how the mockup was cast. When appropriate, have the final procedure translated into the contractor's native language and insure that it is widely circulated among his personnel. Do not allow the contractor to deviate from this procedure without proof that the deviation will be of benefit.

The major advantages of mockups are two-fold: First, completion of a satisfactory mockup insures that the contractor and his personnel understand the requirements for formwork, placement, finishing technique, etc. Second, the completed mockups act as a standard to which the subsequent architectural concrete can be compared for acceptability. Completion of a satisfactory mockup is as much a benefit of the contractor as it is to the Government. If the advantages are explained clearly to the contractor, there should be no problem in persuading the contractor that mockups are necessary and worthwhile.

(2) Sandblasting.

- (a) All sandblasting is required to be carried out within 10 days of placing the concrete.
- (b) No placement on subsequent upper levels is permitted until the lower level has been sandblasted and approved.

11. In order to overcome the deficiencies listed above, and to incorporate some of the techniques being used at KKMC, the following general recommendations are offered:

- a. Additional direction should be provided in expanded Guide Specifications and Instructions to the Architect-Engineer. Additional guidance is needed on the use of design reference sample panels, field mockup sample panels, prebid conferences, preconstruction conferences, and control by sufficient periodic project inspections.
- b. Field personnel should receive training in architectural concrete construction prior to managing an architectural concrete project. Corps project engineers and experienced architectural concrete personnel should follow this by early walk-throughs of placed architectural concrete for evaluation of the training. Such training should include proper use of sample panels, the end product to be expected, proper methods of repair, proper construction procedures, optimum mixture proportions for use with designated textures, and the detection of problems before they become major. Such instructions will provide the QA personnel the confidence required for the decisions that need to be made and implemented. The use of a training and inspector's manual for this type of concrete would be beneficial. Onsite training is, however, of the most value.

- c. The QA program should be revised to place more responsibility for supervision on Corps personnel. This will require adequate training of personnel to provide the necessary experience. Architectural concrete requires more than a check of the final end product. The Corps has excellent architectural concrete where qualified personnel have provided guidance and responsible supervision to the contractor.

### Fact Sheets

12. As a result of the field investigations, 29 repetitive deficiencies have been identified. Their causes and recommendations for prevention and possible repair procedures are included in the following fact sheets. The recommendations for prevention listed in the fact sheets which deal with revisions to guide specifications are being incorporated into the guide specifications by HQUSACE.

Problem: Unsatisfactory bush hammered and ribbed architectural concrete

Causes

Specifications restricted aggregate to nominal maximum size which would have required a 1/2-in. aggregate grading to eliminate the 1-1/2 nominal maximum size noted in the ribs. Exposed by the mechanical hammering these particles will dislodge from freezing and thawing or thermal changes. The finish is described in the specifications as a bush-hammered finish but it is not. A bush-hammered finish for rib construction is bush hammering of the top flat portion of the rib. The finish as shown approaches a fractured rib but was done with mechanical tools in one direction while normally such textures are obtained by manual hammering at the rib on designated intervals and alternating direction. Specifications required removal of loose fragments or splinters which was not done. Rib fracturing was performed too soon as evidenced by the unsplit rock.

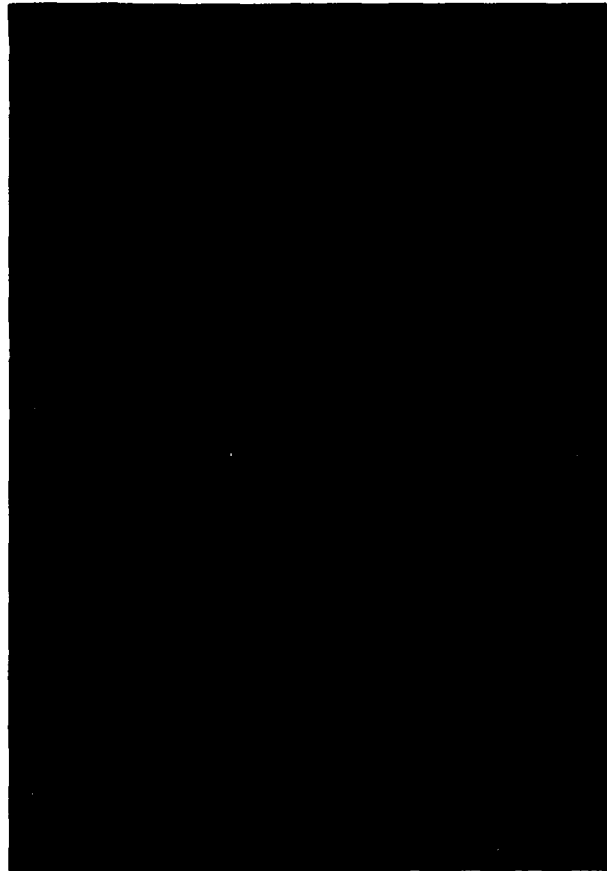
Preventative measures

Have an experienced person review such contractor designs prior to construction. If not available, provide training. Use full-scale sample which can be erected on the building when approved. Write specifications which spell out the desired treatment or use a "reference" sample prior to bid or construction as in this case. Require full-scale sample prior to full production. If not sure of quality, request evaluation by experienced people.

Possible repair procedures

None

Problem: Erected architectural precast panel with unsatisfactory repair



Causes

Panel was not reviewed and rejected at precast plant; project procedure called for approval at jobsite. Unit was erected on rear of building without being reviewed. Repair made with nonmatching mixture which appears to have a high content of integral adhesive material.

Preventative measures

Precast panels should always be reviewed for acceptance at the precast plant as to manufactured quality, but subject to review after arrival onsite for haul damage. Any haul damage should be repaired and approved before erection which will prevent controversy and allow for possible replacement from the plant.

Possible repair procedures

The only available procedure is to remove the repair and replace with another patch matching color and texture.

Problem: Form leakage markings



Causes

Form leakage lines, as shown, are found in sandblasted architectural concrete when the recommended plastic coated form surfaces are allowed to deteriorate. Such cracking in the plastic form coating allows the mortar to leak into the form face and leave a line of cement-rich mortar. Upon hardening, the dark line will not abrade equally with the adjacent concrete. Further sandblasting will only accentuate the difference.

Preventative measures

Inspection of the plastic form face between uses will protect against their re-use unless repaired. If the fine cracks are discovered, the form face can be renewed by additional coats of epoxy. Some benefit can be derived by changing to a lighter cement if compatible.

Possible repair procedures

A needle gun (steel member scabber) can be used to blend out the dark leakage lines. This tool has approximately twenty 1/8-in.-diameter rods which have points. The rods must not be allowed to become dull but must be kept pointed or replaced to be effective. The result is a slightly scaled surface which can then be lightly sandblasted to maintain a uniform texture.

Problem: Color nonmatching concrete



Causes

Possible ways to obtain placement of nonmatching concrete.

1. Use of different cements for the different batches.
2. Contamination of the architectural concrete by use of equipment for mixing, transporting, or placing gray concrete.
3. Using a cleanup load of less than five yards.
4. Misdirection of a structural gray load.

Preventative measures

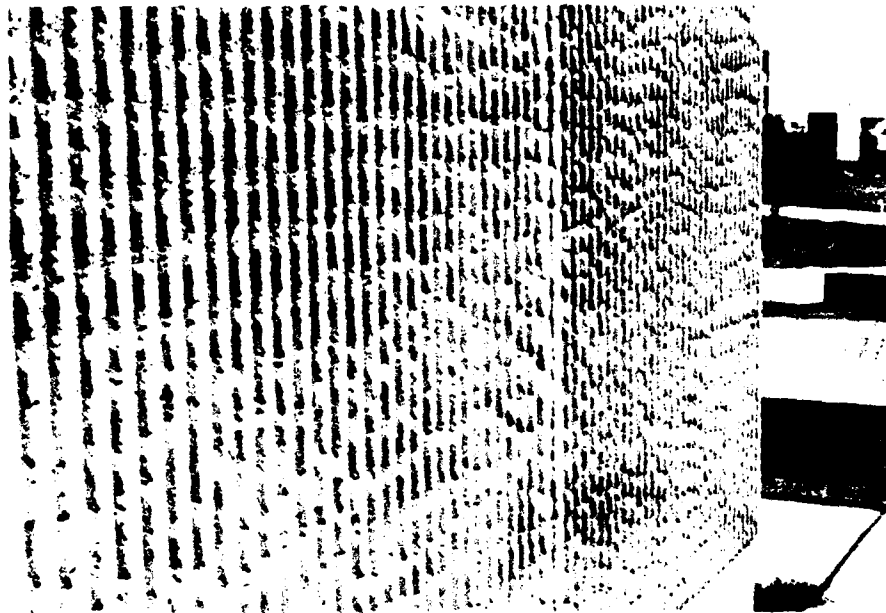
The following precautions can be used for prevention:

1. Use of wet samples to check before use. Such mixtures can be prepared dry and a prescribed amount of water added for preparing the wet sample which is then used as a check against the delivered load for proper color match.
2. Check each concrete delivery ticket to insure proper concrete delivery and source.
3. Schedule placement of architectural concrete first and structural second to insure clean mixing, placing, and delivery equipment. Separate equipment can also be maintained.
4. Use full loads for cleanup loads to insure matching architectural concrete. Remainder is used elsewhere.

Possible repair procedures

Use needle gun to lighten dark area. If ineffective, cut out vertical 1/2 in., apply matching plaster, and sandblast.

Problem: Precast ribbed architectural concrete with nonuniform sandblasting and substandard fractured ribs



#### Causes

Contrast in color of the two sections due to sandblasting at different angles. Near ribbed section sandblasted at three angles to texture rib sides. Far section sandblasted right angles only. Meandering lines of fractured ribs created by mechanical equipment rather than hammers used manually. Defects indicate inexperienced personnel used in construction and acceptance of panels. Field sample (3 ft by 3 ft) was too small to show possible problems.

#### Preventative measures

Supervision and final acceptance by personnel experienced in architectural concrete texturing. Fractured rib texture is normally made by using hammer manually to fracture rib at uniform spacing in alternate directions. As straight line is difficult to hold with chipping or bush hammering equipment, this fractured texture needed a jig or template. Construction of full-size field sample before production phase is good insurance.

#### Possible repair procedures

Additional sandblasting required on far section to abrade sides of ribs and uniform the texture and color of both sections. There is no method of altering the present appearance of the fractured ribs.



Problem: Improper use of field samples



Causes

Project personnel did not require contractor to continue construction of field samples until satisfactory sample obtained. Resulting concrete surfaces on building identical to sample as to misalignment, discoloration, form leakage, amount of bugholes, and roughness of surface.

Preventative measures

Additional field samples required to check for better anchorage of water stop, a change in form surface preparation to remove discoloration, change in mix or vibration to minimize number of bugholes, and change in methods of sealing form joints to prevent leakage.

Possible repair procedures

Needle gun or stone to dress down form leakage lines, and sack with approved method and mixture.

Problem: Bush-hammered texture different between successive lifts



Causes

Bulging of upper form made upper lift thicker. Upper lift bush hammered deeper which exposed more of the aggregate. Form leakage concentrated more aggregate at lift line. Less bush hammering on lower lift. Specifications call for bush hammering to be 1/4 sq ft per minute which relieved contractor of some responsibility for final product. Field sample (4 ft by 6 ft) not of sufficient size to show full height effect of construction joint after bush hammering. No bush hammering done until entire wall cast.

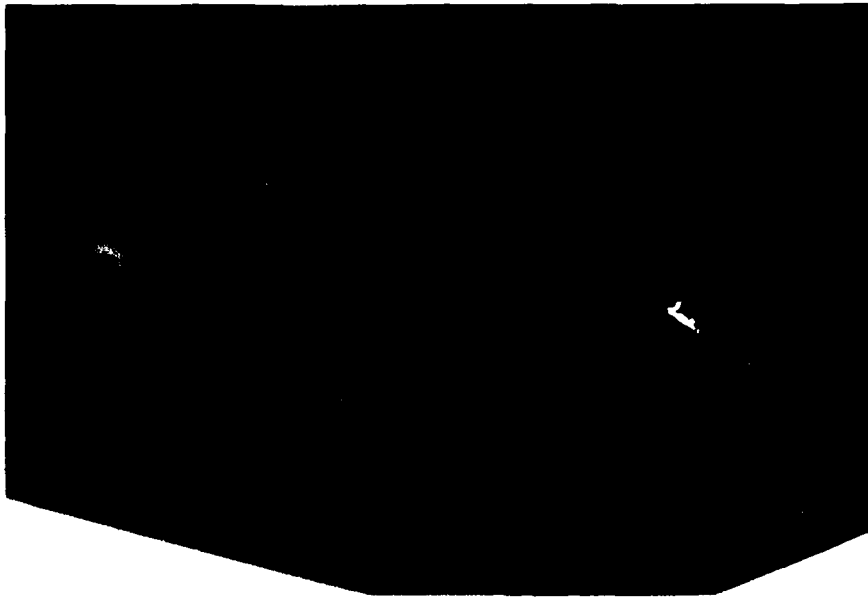
Preventative measures

1. Field sample to have any required construction joint and be bush hammered before start of final wall.
2. Midheight construction joint required by plans should have been deleted. A 10-ft-high form is normal.
3. Use "reference" sample (18 in. by 18 in. min.) to demonstrate color and texture desired. Do not specify how it is to be done.
4. For textured architectural concrete, always have the initial section of the wall or a full-scale field sample treated to see what is happening before proceeding.

Possible repair procedures

Bush hammer portions where little aggregate is visible to achieve uniform exposure. Be careful not to create offsets. If steel cover becomes less than minimum, use sealer.

Problem: Mottled as-cast architectural concrete



Causes

Acceptance due to inexperience or that the surface was not considered architectural concrete. Using a sacking compound rich in gray cement without any white for lightening. Some form release agents will darken the formed concrete.

Preventative measures

Any sacking mixture used for finishing architectural concrete should contain some white cement to match the in-place concrete. A trial section of column, as a field sample, with the proposed forming and methods could have shown beneficial changes to correct this problem.

Possible repair procedures

A "brush" sandblast followed by a sack finish using a mixture containing some white cement will produce a uniform color of the particular structure.

Problem: Unsatisfactory form bolt hole fills in sandblasted architectural concrete



Causes

Filling of the bolt holes prior to sandblasting does not provide the finisher with any guidelines as to color or texture. The abrasion of the sandblasting is greater on the weaker mortar patch, rounds the edges and makes the fill vulnerable to becoming loose.

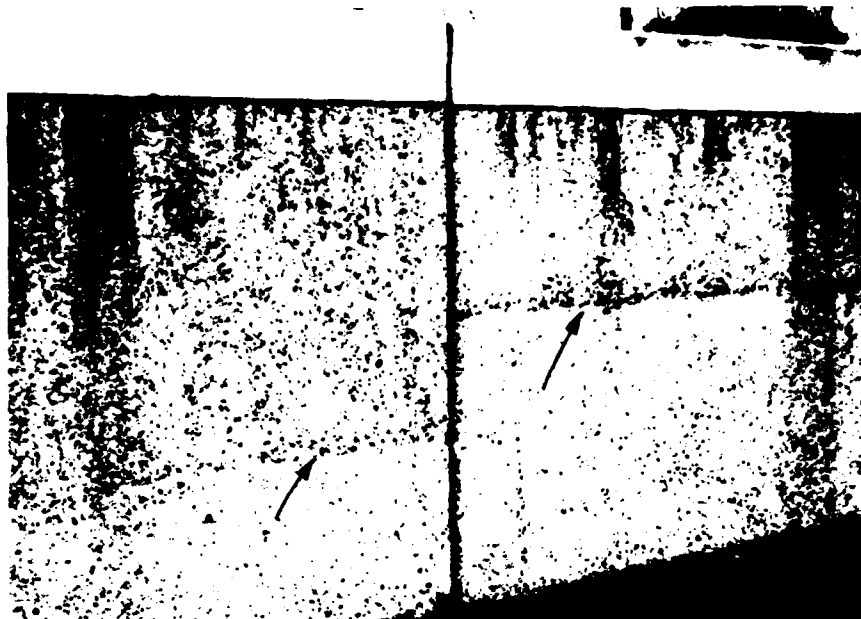
Preventative measures

For textured concrete, do all filling of bolt holes after texturing has been completed with a mixture and a method found to be successful on the field mock-up sample.

Possible repair procedures

Remove tie bolt fills back 1/4 in. and replace with the approved mockup mixture method.

Problem: Offset lift lines in bush-hammered concrete



#### Causes

Project specifications required a change in location of lift line due to shortening of the exposed section of the wall. Form leakage concentrated aggregate at the two lift lines. Subsequent bush hammering exposed the aggregate concentration and accentuated the difference in elevation.

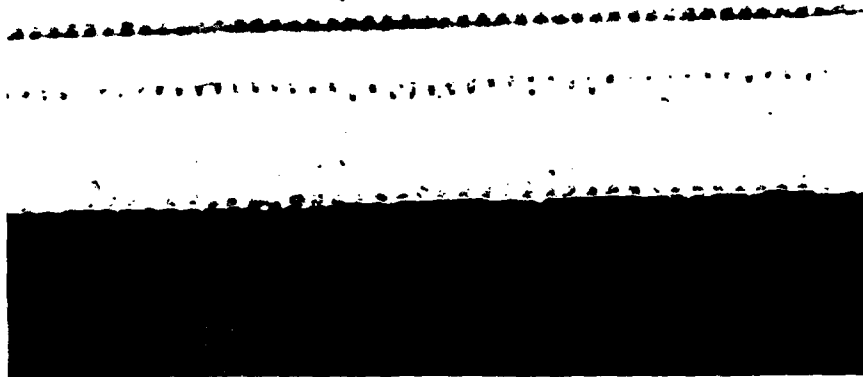
#### Preventative measures

The elimination of the unnecessary construction joint from the plans would have solved the major problem. The leakage could have been prevented by the use of the recommended ACI Committee 303 procedures for such construction joints. Compressible plastic foam gaskets at the bottom of the form have also been used to prevent leakage.

#### Possible repair procedures

There are two possible methods of repairing the present problem. One is to diminish the effect of the aggregate concentration by applying a cementitious mixture containing matching pigments to the area. After sufficient hardening, a needle gun is used to produce uniform appearance and texture. The second method would be to chip out the concentration and replace with a color matching mixture. Upon sufficient hardening, a light bush hammering along this line would provide the required texturing.

Problem: Unsatisfactory as-cast architectural concrete formed with plastic liners



Causes

The horizontal open space has been rubbed or wood-floated with a mortar mixture to fill the surface air voids and possibly additional areas where the concrete surface was peeled during stripping. The mortar has been forced down between the lower ribs and not cleaned out. The leakage at the bottom of the form has left a projecting flange which is not being removed. An attempt has been made to produce a uniform color of the ribbed surface by application of a proprietary material which has not been satisfactory.

Preventative measures

Require finisher to complete his work prior to hardening of the concrete. Specifications should not allow contractor to apply a coating as it does not inspire him to do good work. Additional vibration and slower removal will eliminate most of the bugholes seen in the photograph. Ask for job sample panel.

Possible repair procedures

Have finisher clean out mortar between ribs. Appearance will be more uniform if coating left off.

Problem: General appearance of field sample unsatisfactory when sandblasted



Causes

Dark lines due to form leakage. Vibration insufficient as settlement cracking visible. Sandblasting delayed sufficiently to cause mottling.

Preventative measures

Suggest better sealing of form joints, additional vibration, and earlier sandblasting on second mockup. If mottling is still present, a change of cement may be required. Try third field mockup sample. Satisfactory sample should be obtained prior to commencing construction of production forming. Make sure that any field sample will be true sample of the contractor's operation. On some projects, interior or basement wall of similar size to the architectural concrete which will be covered or hidden by subsequent construction, has served as a field sample.

Possible repair procedure

Field sample is excellent opportunity to try repair procedures, as it allows time for color fading of various trial repair mixtures and test skill of finisher prior to main effort on building.

Problem: Nonuniform surface appearance in sacked as-cast concrete surfaces



Causes

Following the present specifications literally and requiring the sacking of architectural concrete within 48 hr of form removal will cause the above nonuniform appearance as each sacking has been done at different times.

Preventative measures

Hold sacking for such members until member has been completed. Any repairs to surface blemishes should still be held to the 48-hr limit except when the concrete is to be textured. Such repairs should be completed after texturing.

Possible repair procedure

After "brush" sandblast, spray-apply a fine sand and acrylic mixture over the member sufficiently to produce uniform color.



Problem: Improperly repaired crack

#### Causes

This repair is one of most difficult because it is irregular and may be a working crack. Acrylic adhesive required to insure bonding and permanence has a tendency to darken the mixture and produce a gloss if an excessive quantity is used. The mixture has a deficiency of the fine aggregate which would impart some light coloring.

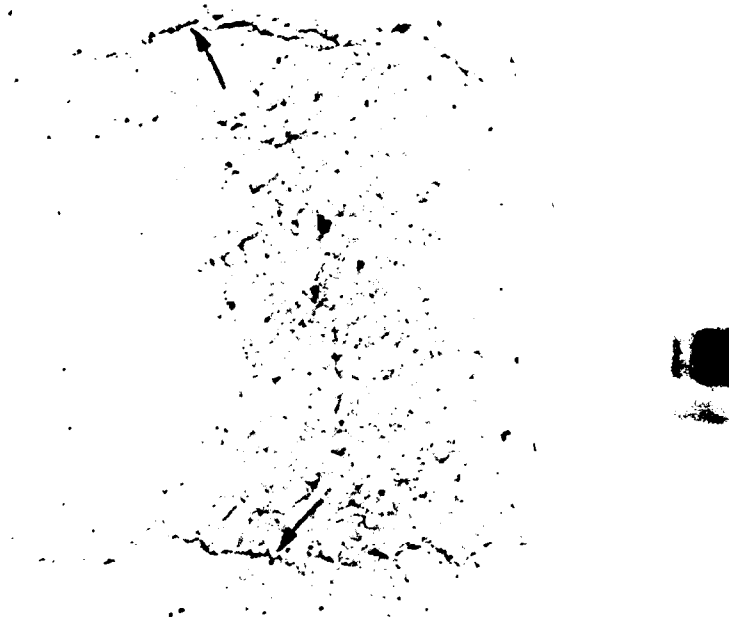
#### Preventative measures

In most cases, it is better to live with a crack unless it seriously detracts from the architectural appearance. If patching is required, make trials on field mockup or in unimportant areas. Try various quantities of color, sand size particles, and amounts of acrylic. In addition, various widths of repair should be tried as a wider repair might have allowed larger sand particles and better matching capability. Allow a minimum of 30 days of aging for proper color match.

#### Possible repair procedure

Chip out and repair in accordance to procedures developed on field mockup sample.

Problem: Subsidence cracking



Causes

Subsidence cracks are due to insufficient vibration followed by subsidence of the concrete. They are most evident when followed by sandblasting for architectural effect. The initially fine cracking becomes widened due to rounding of the surface edges and unsightly. Can occur with high-range water reducers accompanied by insufficient vibration or lack of any vibration.

Preventative measures

Check amount of vibration required on field mockup to prevent this cracking. Additional revibration with regular concrete will also minimize such cracking. Some vibration be used with high-range water reducers for consolidation.

Possible repair procedures

Widening and refilling with a color and aggregate matching mix. This should be followed by a special light sandblasting for final texturing. Before any attempt on the final structure, trial attempts should be made on the field sample or portions of the structure later covered. The mixture must also integrally contain some acrylic type adhesive.

Problem: Unsatisfactory sandblasted architectural concrete



Causes

Precast stairs placed in the form and the wall cast around them. Sandblasting of the surface has produced the contrast between the two mixtures. The bottom area is a form bulge which was bush hammered back and is now contrasting with the light sandblasted finish because of the exposed aggregate.

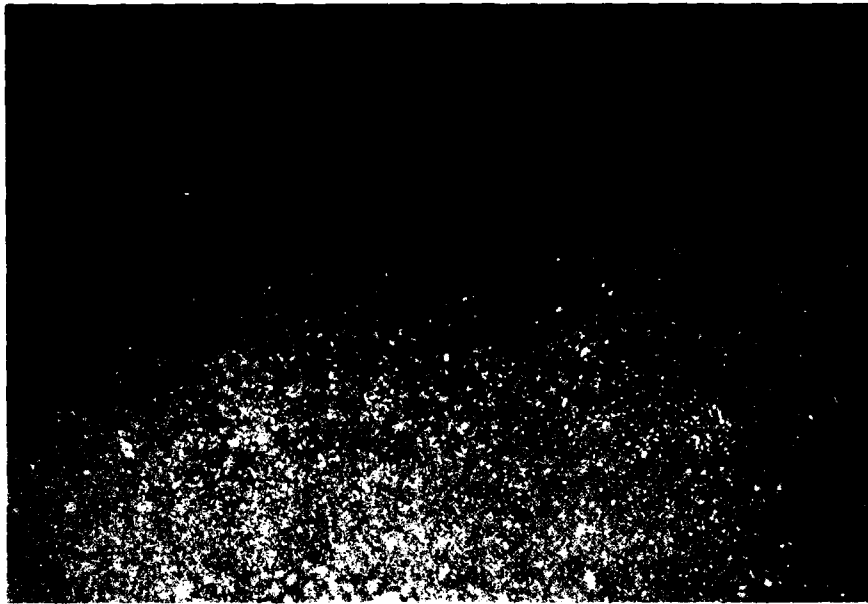
Preventative measures

Better form bracing to prevent bulging. Upon occurrence, removal and replacement of such architectural concrete before additional concrete is placed above it. Acceptance of its future repair indicates lack of understanding of the finish. Precast and cast-in-place concretes are difficult to match in color. In this case, the stairs could have been supported on a thicker lower wall so that they could be inset a few inches from the outside and covered by the wall concrete.

Possible repair procedures

A color matching cement wash applied over the entire surface. A light sandblast applied after good hardening will make the surface uniform. As this a tunnel exit, the same treatment must be done to the other side.

Problem: Dark blotches on surface of sandblasted architectural concrete



Causes

Pattern of blotches indicates form splatter by concrete not remixed during subsequent vibration and concrete placement. High cement contents, early setting, and late sandblasting resulted in a mortar harder than the light colored limestone aggregate. Additional sandblasting caused more contrast by abrading the aggregate faster. The resultant dark streaks are accentuated here by the form splatter. The coarse aggregate amount is insufficient to overcome the color contrast.

Preventative measures

Thin metal or polyethylene sheets inserted into the forms prior to placing concrete and removed as the concrete level rises will effectively protect the form face from mortar splatter. The contrast of the dark streaks could be overcome with the use of a white or light cement approaching the color of the aggregate, or by lowering the gray cement content with a corresponding increase of coarse aggregate and sandblasting earlier when the mortar is weaker.

Possible repair procedures

Stop sandblasting as soon as the condition becomes apparent. Remove the dark areas with a needle gun and resume sandblasting to achieve texture. Do not attempt to remove dark areas too deeply and create a noticeable depression. Allow the sandblasting and time-dependent bleaching to correct the contrast.

Problem: Improper use of coatings on architectural concrete



Causes

Proprietary coating is too thick and has completely obscured the intended architectural appearance expected from the use of a plastic form liner. Brush application rather than spray has added the bumpiness and marking which is detracting from the appearance. The result does not appear to have acceptable durability.

Preventative measures

Eliminate use of coating as it detracts rather than adds to the architectural appearance of the surface. Sacking for as-cast finishes are more effective and produce a more durable product. Proper maintenance of plastic form liners and ample vibration will produce an excellent as-cast surface. The maintenance of the form liner requires application of release agent for each use, sealing of the joints against leakage, proper fastening to the base form, and proper care during handling. To minimize bugholes, after sufficient vibration for consolidation, removal of the vibrator should be at a rate of 3 in. per second.

Possible repair procedures

Add spray on coating in a vertical fashion to achieve a uniform coating.

Problem: Color contrasting precast panels



Causes

The as-cast precast panels contain three different cements. Bottom to top, they are a light Spanish cement, a Saudi Arabian Type I cement and a Saudi Arabian Type V cement. Light or brush sandblasted finishes will show contrast if sand sources change and the sands are of different colors.

Preventative measures

Insure one source of cement and aggregate, one mixture, and if textured, only one type of texture.

Possible repair procedures

There is no repair for an as-cast surface except time and weather to lighten the concrete. Changing a light or brush sandblasted surface to medium will lighten the surface and allow the exposed aggregate to predominate. Never attempt to correct a sandblasted surface by bush hammering or bush hammered surfaces by sandblasting unless the entire surface is redone. The effectiveness of a needle gun is due to a minute chipping action producing a texture between both types.

Problem: Poor quality rustication



Causes

The contractor did a good job as regards formwork design by incorporating vertical rustications at construction joints in a medium sandblast wall. Unfortunately, untreated lumber was used to form the rustication and this absorbed water from the concrete. The result was that the concrete in contact with the rustication, having a reduced water cement ratio, and was harder than the remainder of the concrete. Consequently, the sandblasting did not abrade this concrete sufficiently, leaving a line with very little aggregate exposed.

Preventative measures

Always use material to construct formwork which is nonabsorbent.

Possible repair procedures

Localized chipping with a pneumatic needle scaler may help to expose more of the aggregate.

Problem: Poorly constructed formwork at the corner of a cast-in-place column



#### Causes

The corner of the formwork was not sealed adequately, causing a considerable loss of mortar, resulting in a honeycombed appearance after sandblasting. Also, the material used for the corner chamfer strip was plain, unsealed lumber. This caused water from the concrete to be absorbed by the lumber which reduced the water-cement ratio and increased the strength of the concrete. Consequently, the sandblasting would not remove the matrix of the harder concrete.

#### Preventative measures

Good quality form materials and formwork construction:

1. Seal all joints adequately to prevent leakage;
2. Use nonporous material such as sealed lumber for corner chamfer strips.



#### Possible repair measures

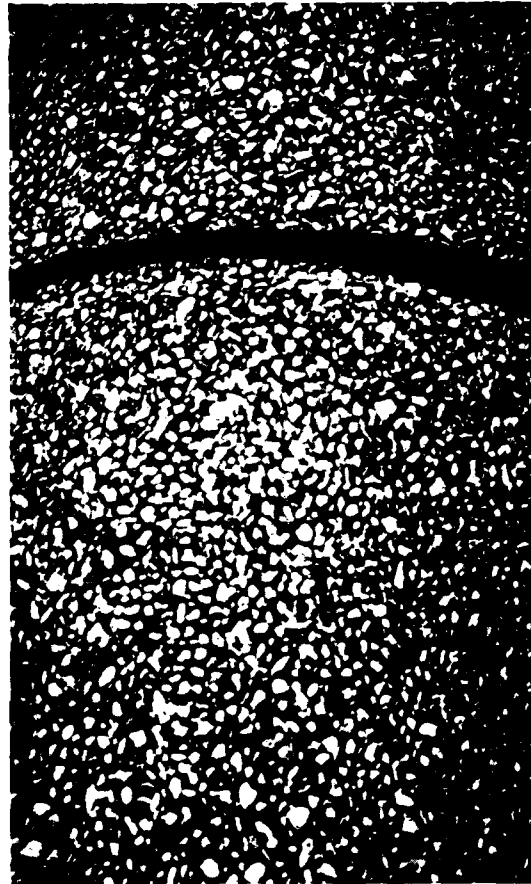
Satisfactory repair of this defect is difficult, due to the occurrence of the two defects in close proximity. The line of slight honeycombing would best be repaired by filling in the voids with a matrix composed of cement, sand, water, and bonding compound to match the color and texture of the matrix of the parent concrete. Sponging the excess mortar off to expose the aggregate before the mortar completely sets. The hardened area where the sandblasting did not expose the aggregate should be worked on with a pneumatic needle scaler.

Problem: Areas in medium sandblast columns devoid of coarse aggregate

After Sandblasting



After Repairs



#### Causes

These defects, commonly known as "sand streaks" are caused by allowing the internal vibrator to come close to the form. This causes the vibration to force the coarse aggregate away, leaving a vertical streak of matrix devoid of coarse aggregate. This problem is more prevalent when superplasticized concrete is used as the fluidified state of the concrete enables the vibration to move the coarse aggregate with greater ease.

#### Preventative measures

Ensure that the internal vibrator does not come into contact or close to the form at any time.

### Possible repair procedure

This procedure has been successfully used at KCMC:

1. Roughen surface of sand streak by going over it with a needle scaler.
2. Apply painted-on aggregate to the roughened surface using the following technique:

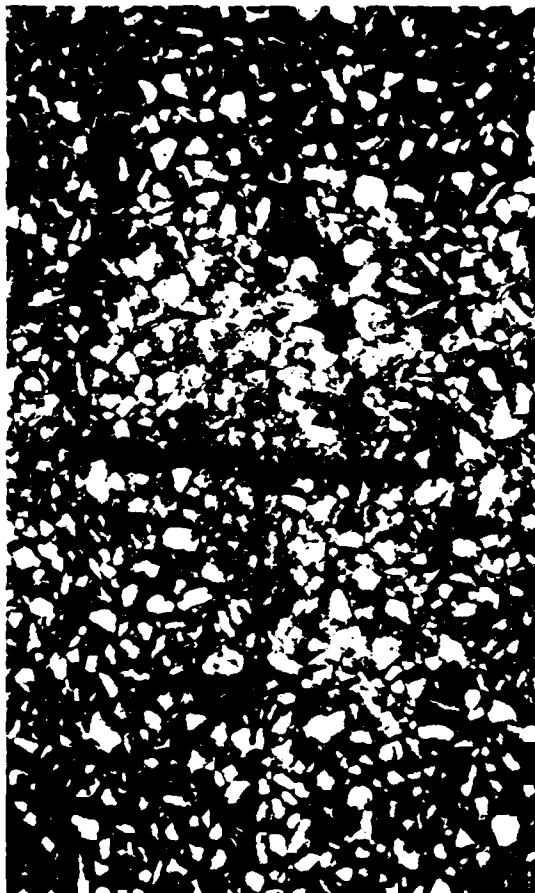
Small areas of sand streaking which are not big enough to warrant cutting out or areas where the density of coarse aggregate is marginal, can be enhanced by using the painted on aggregate technique. This involves artistically painting on a mixture of cement, sand, water and bonding agent to simulate the missing aggregate. The paint mix is as follows:

- 1 part cement (mixture white and gray with the proportions varying depending on the color required)
- 2 parts fine aggregate (mixture of -#16 sand and stone dust, proportions varying as per the above)

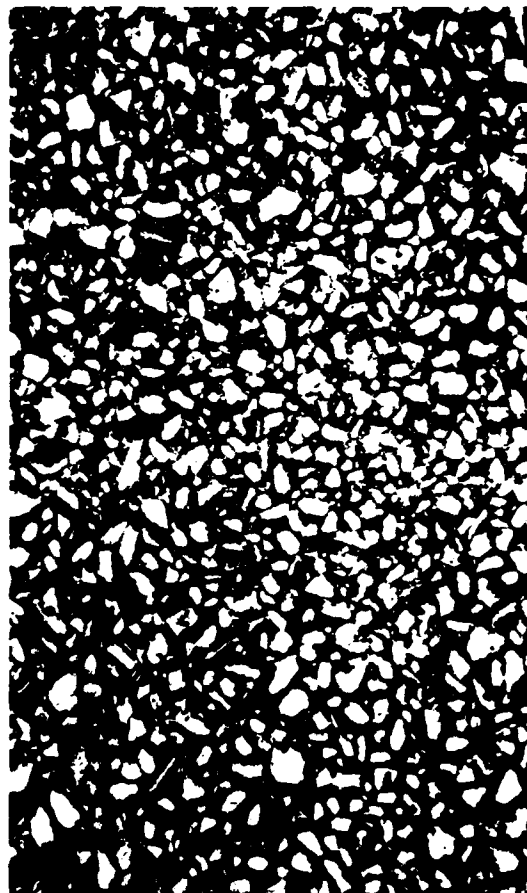
The above is mixed with a solution of one part acrylic adhesive to three parts water to a consistency of thick pea soup. It is imperative that adhesive is mixed with water, without it the repair can be rubbed off with virtually no effort. It is then applied to the concrete in limited quantities to simulate the natural aggregate, various shapes and a random application is necessary. Normally two or three different color variations are used together to blend in with the natural aggregate. No surface preparation of the concrete is required before or after painting as the fairly viscous paint is partially absorbed by the porous mortar patch. The application of the painted repair technique must be closely controlled as it is easy to apply and cannot be permitted to become a cover up for bad workmanship.

Problem: Form leakage on medium sandblast finish

After Sandblasting



After Repairs



#### Causes

In this case, where steel forms were in use, the leakage was due to the rubber gasket between the mold edges being worn and needing replacement. The black lines which occur at the location of the leakage are caused by a concentration of cement fines causing a change in water cement ratio in the immediate locality. This creates a harder matrix, which the normal sandblasting will not remove. In other cases where plywood forms are used, similar problems will occur if the form joints are not completely sealed.

#### Preventative maintenance

Formwork for architectural cast-in-place concrete must be sealed. Joints can be sealed in various ways, such as non-absorbent caulking, gasketing, mitering and gluing, taping (only on medium or heavy sandblast or bush-hammered finish). In each of the foregoing methods the joint should be backed up with 2-in. by 4-in. timber brace nailed to both. Another satisfactory method to seal the

joints in the plywood is to eliminate them by using a smooth vinyl formliner (see attached sample). The forms are gang formed into the largest reasonable size and the complete surface covered with formliner applied with contact adhesive. Care being taken that the joints in the formliner and the plywood backing do not coincide. At each joint between gang forms or at each construction joint a rustication should be used to minimize the chances of leakage, noticeable offsets, etc., and to provide a crack control joint.

#### Possible repair procedures

1. A large percentage of the black line can be removed with a pneumatic needle scaler.
2. Any remaining areas in which the black mark is not removed and the aggregate exposed with the needle scaler can be treated with the painted on aggregate technique as described in the preceding problem data sheet on sand streaks.

Problem: Vertical crack in sandblast wall



Causes

The crack is caused by thermal movement and drying shrinkage. The crack probably occurred within a week of placing the concrete and was accentuated by the sandblasting which took place after the crack occurred.

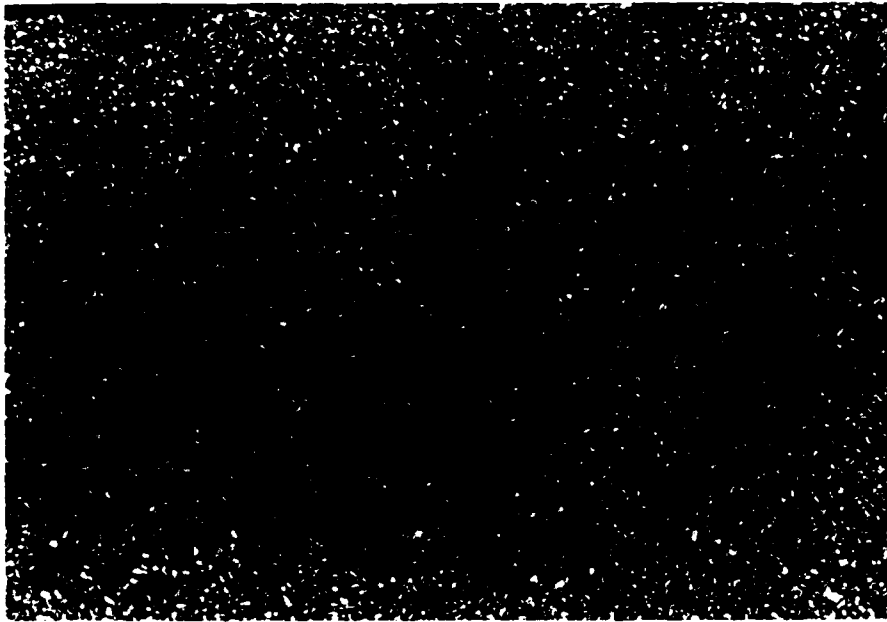
Preventative measures

Vertical crack control joints with rustications are provided at 20-ft centers; this is too far apart for hot arid climates subject to maximum temperatures of over 120° F and daily variations in excess of 50° F. Crack control joints, with rustications, should be provided at 10-ft centers. Also, the problem would be minimized if the sandblasting was done earlier before the concrete had cracked.

Possible repair procedures

1. Use epoxy injection to seal the crack.
2. Chip out wider portions of the crack and repair by filling with color compatible mortar and seeding with aggregate.

Problem: Horizontal cracks in medium sandblast wall



Causes

This represents settlement cracking due to improper or no vibration.

Preventative measures

Ensure that the rebar has the correct cover prior to commencing placement.

Possible repair procedures

Fill in the cracks with mortar which is color compatible with the concrete and seed with aggregate where necessary.

Problem: Cement block rebar spacers used on exposed beams



Causes

The contractor used cement mortar blocks as reinforcing steel supports and spacers on exposed form finish beams.

Preventative measures

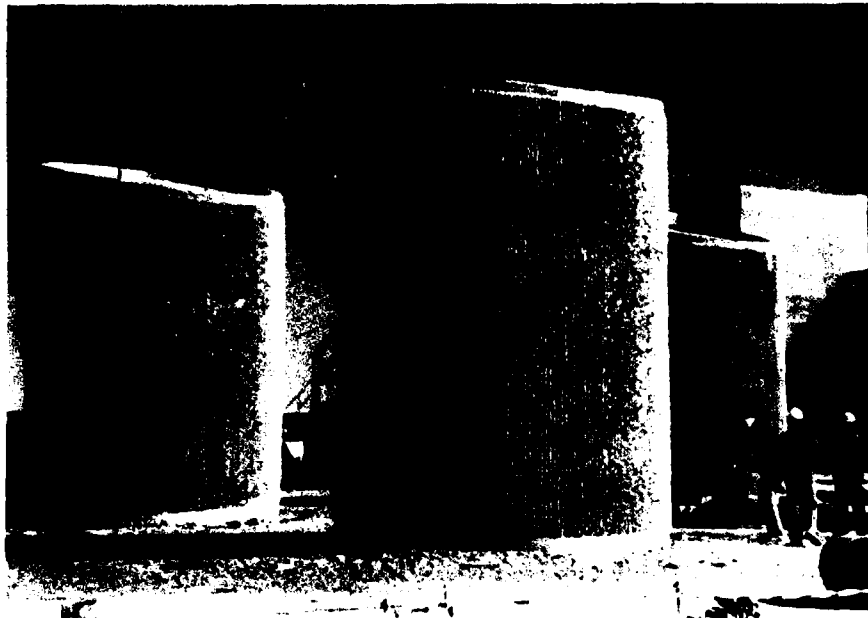
Do not permit the use of cement blocks as rebar spacers on exposed concrete surfaces. Use plastic chairs or spacers.

Possible repair procedures

1. Cut out the cement mortar blocks and patch with a cement mortar with a color more compatible with the concrete.
2. Cement rub the complete beam in accordance with the following requirements: "Rubbed concrete finish shall consist of thoroughly wetting and then brush-coating the surfaces with cement grout composed of one part portland cement to not more than two parts fine aggregate passing the No. 30 mesh sieve (by volume), and mixed with water and a proprietary acrylic or latex bonding compound to the consistency of thick paint. White portland cement shall be used for all or part of the cement and shall be proportioned as determined by trial mixes, so that the final color of grout, when dry, will be approximately the same as the color of the surrounding concrete. Grout shall be cork- or wood-floated to fill all pits, air bubbles, and surface holes. Excess grout shall be scraped off with a trowel and the surface rubbed with burlap to remove any visible grout film. The grout shall be kept damp by means of fog spray during the setting period but not less than 24 hr. The finish of any area shall be completed in the same day."



Problem: Poor quality construction joint in hammered rib chimney



Causes

The 20-ft- (6-m) high chimney was cast in two placements of approximately 13 ft (4 m) and 7 ft (2 m). The construction joint between the castings was not very well done. The upper form was not sealed tightly against the lower placement and there was considerable leakage.

Preventative measures

1. The best method to have prevented the problem would have been to have cast the chimney in one placement, thereby eliminating the construction joint.
2. Alternatively, a horizontal rustication could have been used at the construction joint which would have facilitated the sealing of the form.

Possible repair procedures

After hammering the ribs, clean off the laitance which has leaked down and if necessary cement rub the smooth portion of the casting.

Problem: Exposed plastic rebar spacers on sandblast column



Causes

Used the wrong type of plastic rebar spacers. Used the type which leave an approximate 1/2-in. by 1-in. area of black plastic exposed after sandblasting.

Preventative measures

Use the correct spacers, such as the circular disc type or the star shape which have a minimum of the spacer in contact with the form. Also use spacers made from plastic of a color similar to the concrete.

Possible repair procedures

Cut out exposed spacers and patch.

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